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ABSTRACT

Suggestions for instructional improvement are offered for science teachers in this compilation of research summaries on specific areas of science education. This series includes the articles: (1) "Improving Students' Understanding of the Nature of Science" (discussing the relationship between teachers and students conceptions of science and identifying the classroom variables related to changes in students conceptions of science); (2) "Selecting and Using Science Textbooks" (presenting research-based guidelines for selecting science textbooks); (3) "Sequencing Learning Activities in High School Chemistry and Physics: the Learning Cycle Approach" (reviewing the characteristics and advantages of the Piagetian developmental theory that divides instruction into three phases); (4) "Using Wait Time to Improve the Quality of Classroom Discussions" (reporting the effects of increases in the pauses, i.e., wait time, of teachers and students in classroom interaction); and (5) "Pupil Behavior and Motivation in Eighth Grade Science" (reporting possible factors related to achievement and student involvement in active learning). (ML)

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RESEARCH MATTERS...TO THE SCIENCE TEACHER

VOLUME 1, 1984

Ann Howe, Editor

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Research Matters...To The Science Teacher

IMPROVING STUDENTS' UNDERSTANDING OF THE NATURE OF SCIENCE

By Norman Lederman

Scientific literacy is a primary aim for science education in the 1980's. An important component of scientific literacy is an adequate conception of the nature of science. Three decades of research on students' conceptions of the nature of science—the values, assumptions, and processes upon which scientific knowledge is based—have given us little more than the knowledge that we are unhappy with the conceptions possessed by our students. Researchers have assumed that a significant positive relationship exists between teachers' conceptions and changes in students' conceptions. This assumption has remained virtually untested.

The initial purpose of this research was to assess the validity of the assumption that teachers' and students' conceptions are significantly related. Secondly, and most importantly, this research identifies classroom variables that are related to changes in students' conceptions of science.

Method

For this study 18 senior high school biology teachers and their students were selected randomly from nine public schools. All instruction followed the New York State Regents biology syllabus which is college preparatory in its orientation. Both teachers and students were tested on the "Nature of Scientific Knowledge Scale" before and after instruction. This scale measures a respondent's conception of the nature of scientific knowledge. In addition, intensive qualitative classroom observations were made in each of the classrooms between pre-and posttests. Subsequent analysis of classroom transcripts permitted both qualitative and quantitative comparisons between classrooms showing large changes in students' conceptions and those showing little change.

Results and Conclusions

Correlations between teachers' and students' Nature of Scientific Knowledge scores were low and did not support the contention that changes in students' conceptions of science are related to their teachers' conception of the nature of science. This result does not imply that a teacher is able to teach what he/she does not understand, but rather that beyond some essential level of knowledge or understanding a teacher's viewpoint is not significantly related to change in students' viewpoints. This reinforces the importance of *teacher behavior* and *classroom climate* with respect to student outcomes. Indeed, it invites the question asked by the major portion of this research: What classroom variables are related to changes in students' conceptions of science?

We have called teachers/classrooms that showed large conceptual changes by students successful. We found that they had frequent inquiry-oriented questioning with little emphasis on rote memory/recall and seat work. Teachers in these classrooms were pleasant, supportive, and frequently used humor and anecdotes to promote instruction and establish a healthy rapport. As might be expected, successful classrooms were more often characterized by attentive students who were actively engaged with materials and subject matter. Explicit comments by teachers concerning the tentative, testable, and amoral aspects of scientific knowledge were common.

Successful teachers/classrooms appeared to stress depth, breadth, and accuracy of content more often than the unsuccessful teachers/classrooms.

Implications for Science Education

The lack of a significant relationship between teachers' conceptions of science and changes in students' viewpoints clearly directs attention to the importance of a teacher's classroom behavior and the classroom atmosphere he/she establishes. Although teachers have been criticized in the past for failure to promote adequate student conceptions of science and are currently being rather strongly urged to do so, they have not been offered any useful advice on how to accomplish such an important goal.

An interesting issue is raised when one considers the current interplay between the "back to basics" and "scientific literacy" movements. Researchers have commented on the positive effects of drill and emphasis on lower-level understandings with respect to simple/concrete student understandings consistent with the intent of the "back to basics" movement. However, attention to drill and lower-level understandings were found in this study to be detrimental to students' conception of science, while stress on higher level understandings and inquiry were strongly associated with changes in students' conceptions of science. Since an adequate understanding of the nature of science is an attribute of the scientifically literate individuals the situation is ironic. The current educational atmosphere is placing stress on achieving both content outcomes and the more abstract "nature of science" outcomes, but it appears that different teaching techniques are needed for these outcomes. Since teachers are often evaluated on the basis of students' scores on achievement tests which predominantly measure lower-level knowledge, the plea for increased student scientific literacy may be asking for the accomplishment of the impossible!

It is clear that teachers who want to increase students' understanding of the nature of science and thus increase their scientific literacy must pay careful attention to what they say and do in the classroom and to the kind of classroom climate they establish. It is not enough for a teacher to have an adequate concept of the nature of science; he or she must *communicate it* to students.

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For a complete copy of the research described contact the author at 101 Heroy Hall, Syracuse University, Syracuse, NY 13210.

Research Matters...To The Science Teacher

SELECTING AND USING SCIENCE TEXTBOOKS

By William G. Holliday

Selecting Science Textbooks

Here are some research-based guidelines useful in selecting science textbooks. Ask yourself these questions:

- Are the diagrams, line drawings, tables, graphs, charts and photos adequate and directly related to the printed text? Do they really help?
- Are the concepts and processes accurately presented in an integrated and meaningful fashion?
- Are there variations of bold-faced type and other typographical cues useful in highlighting important ideas—explicitly clarifying the relationships among ideas and their examples?
- Is the book edited in an appealing fashion with effective illustrations, with an easy-to-comprehend organizational style, with glossaries for pronunciation and meaning, with summary statements throughout the book, and with sentences and a vocabulary of reasonable complexity?
- Does the textbook contain helpful learning aids such as study questions that help focus attention, organize ideas and encourage thinking, and highlighted statements relating the text to laboratory experiences and student projects?

Research related to science textbooks suggests that good books have the following features:

- many concrete, explicit examples
- simplified, "bareboned" explanations
- consistent organizational patterns among chapters
- content compatible with students' prior knowledge and skills and
- absence of clutter, tangential ideas, unnecessary modifiers, and meaningless jargon.

Do *not* select a science textbook on the basis of popular readability formulas or word-list procedures. Ignore them. Experts tell us that these popular procedures can be used easily but often end up spelling disaster for students. These strategies are *not* valid and are *not* reliable. (Do not be fooled by some well-meaning but uninformed textbook salespersons, science supervisors, "experienced" teachers, and even some reading "specialists.") *If you must* use a mechanical strategy for estimating the appropriateness of a textbook in terms of the readability load placed on students, then give careful consideration to using, on a trial basis, a customized cloze procedure. In this procedure students are given a reading sample in which "key" words have been deleted and are requested to guess or infer the deleted words.

Using Science Textbooks

Uses. Science teachers use textbooks in a variety of ways, including use as a source where students can learn about concepts and processes, can fill in the gaps after hearing a lecture and consult as a reference when preparing a paper or project.

Reasons. Textbooks can be organized in an easy-to-learn fashion, can provide students with an efficient means of learning science, and can present material in a form similar to the printed medium to be used later in adulthood.

Aids. Science teachers need to use study questions and other devices that require students to think, to comprehend, and not just to copy definitions and phrases word-for-word directly from the textbook. You can bet that students will copy answers to questions verbatim if given a chance about 9 out of 10 times. Do not use verbatim, recall, or knowledge questions except very rarely.

Links. Research suggests that science teachers should always help students by linking previous content to the new content contained in freshly assigned chapters of a textbook.

Students, especially poor readers, need to be shown how

- the chapter is organized
- to recognize important ideas
- the most important ideas relate to subordinate ideas
- figures and tables relate to the text
- to use learning aids contained in the text.

Teachers should also consider encouraging some students to use on a trial basis such study techniques as outlining and diagramming ideas contained in the text, note taking from the text, special review procedures, using study questions, and underlining—all of which are suggested by recent research results.

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Research Matters...To The Science Teacher

SEQUENCING LEARNING ACTIVITIES IN HIGH SCHOOL CHEMISTRY AND PHYSICS: THE LEARNING CYCLE APPROACH

By John W. Renner, Michael R. Abraham, and Howard H. Birnie

The Learning Cycle Approach is a generalized teaching model which can be useful for teachers in designing curriculum materials and instructional strategies for science. The model is derived from the developmental theory of Jean Piaget and divides instruction into three phases: (1) the Gathering Data phase (G); (2) the Conceptual Invention phase (I); (3) the Conceptual Expansion phase (E). Each of the phases and the sequence of the phases is consistent with how individuals of all ages learn concepts.

Each learning cycle begins with an activity which gives students experience with the concept to be developed, usually a laboratory experiment. In contrast to traditional approaches the laboratory serves as an introduction to the concept rather than as a way of confirming the validity of a concept presented earlier. This is followed by the second phase of the Learning Cycle where the teacher and/or student literally invent the concept from the data. This is usually carried out during a classroom discussion. It's useful to point out that the sequence of the first two phases (data leading to concept) is the reverse of that carried out in traditional instruction (concept learning to supporting data). The final phase activities give the student the opportunity to expand the meaning, usefulness, and general understanding of the newly invented concept. This is usually carried out through a variety of activities including additional laboratory experiments, problem sets, readings, and demonstrations.

Students distinguish Learning Cycle Approaches from traditional approaches in the following ways:

- Learning Cycle Approaches emphasize the explanation and investigation of phenomena, the use of evidence to back up conclusions, and the designing of experiments.
- Traditional approaches emphasize the development of skills and techniques, the receiving of information, and the knowing of the outcome of an experiment before doing it.

The Learning Cycle Approach is a viable teaching model that has many advantages over traditional instructional approaches especially for concrete operational students. Since a large proportion of the secondary school population is not yet formal operational, it seems a reasonable conclusion that the Learning Cycle Approach deserves more widespread implementation in school science classrooms.

Two large scale studies of the Learning Cycle were recently carried out to investigate three questions: (1) are all three of the phases of the Learning Cycle necessary for optimum learning?, (2) is the sequence of the three phases important?, and (3) how does the form in which the instruction is delivered (e.g., laboratory, reading, lecture, demonstration, etc.) influence learning? Data concerning both achievement and attitude were gathered and analyzed.

The study concerning high school chemistry consisted of typical students and had a mix of 50% concrete operational and 50% formal operational students. Results are summarized below:

(1) All three phases of a learning cycle are necessary for the optimum learning of concepts.

(2) Students prefer complete learning cycles—i.e. those with all three phases. Exception...if expansion phase is long and complex.

(3) The Expansion and Gathering Data phases of the learning cycle are interchangeable. They play their role by virtue of their position. It is the position of the Invention phase that determines the sequence of the phases of the learning cycle.

(4) For review concepts:
Concrete operational students: Learning Cycle sequences which have the invention as the last phase are superior to other sequences in content achievement.
Formal operational students: Learning Cycle sequences which have the invention as the first phase are superior to other sequences in content achievement.

(5) For new concepts:
Learning Cycle sequences which have the invention as the second phase (normal sequence) are superior to other sequences in content achievement.

(6) In attitude, sequences which have the invention coming after the first phase (i.e. either second or third) are preferred by students.

(7) Laboratory formats are superior to lecture or reading formats in content achievement for concrete operational students.
(8) Reading formats are effective for formal operational students, but ineffective for concrete operational students in content achievement.
(9) In attitude, laboratory formats are thought of most positively and reading formats are thought of most negatively by students.
(10) To be effective, laboratory must be used in conjunction with discussion as in the Learning Cycle sequence of Gathering Data, Inventing the Concept. The laboratory must provide clear concrete data leading to the concept.

The research concerning high school physics consisted of a student group about 90% formal operational. The following statements summarize the results of that research.

- All three phases of the learning cycle are necessary to lead physics students to the maximum learning possible.
- In individual interviews the students stated very clearly that they believe all three phases of the learning cycle are necessary when studying physics.
- The statistical data indicate that the sequence of the phases is unimportant to the physics group *if* all three phases are taught.
- The students believe that the sequence of the Learning Cycle's phases is important to how they learn physics and prefer the regular sequence. In particular, the students do not like to discuss a concept until they have gathered their own data from an experiment.
- The form in which the students experienced the phases of the learning cycle did not influence their knowledge of content.
- Students believe they learn more physics content more easily if they first use apparatus to gather data (G), discuss the meaning of the data (I), and have experience which expands their meaning of the concept (E).
- When most of the members of a group have reached the formal operational stage, they can profit from instruction that is not given at an experiential level. However, when students' data from the laboratory are not used as the principal source for building concepts, and reading about or being told about the concepts are substituted for laboratory experience, the students do not like it and become bored quickly.

We believe that research lays a solid foundation for justifying implementation of Learning Cycle Approaches in school science.

Specific Recommendations to Teachers

1. Prior research has shown that the Learning Cycle Approach to teaching is superior to traditional approaches. We recommend, therefore, that secondary school science teaching adopt the Learning Cycle Model for teaching and curriculum construction in chemistry and physics.
2. Using all phases of the learning cycle in teaching chemistry and physics produces the most effective learning.
3. For most effective student attitudes and learning, the form and sequence of the learning cycle should be (1) Gathering of data by students, (2) Discussion of data by students and teacher, and (3) Expanding the Concept found in the data.

This research is described in the following publications:

1. Abraham, M. R. and Renner, J. W., *Sequencing Language And Activities In Teaching High School Chemistry: A Report To The National Science Foundation*, University of Oklahoma Science Education Center, Norman, Oklahoma 1983.
2. Renner, J. W., Abraham, M. R., and Birnie, H. H., *Sequencing Language And Activities In Teaching High School Physics: A Report To The National Science Foundation*, University of Oklahoma Science Education Center, Norman, Oklahoma 1983.

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Research Matters...To The Science Teacher

USING WAIT TIME TO IMPROVE THE QUALITY OF CLASSROOM DISCUSSIONS

By J. Nathan Swift, C. Thomas Gooding, and Patricia R. Swift

You have probably heard many teachers start their sessions by saying "Today, we are going to discuss...." Based on our examination of classroom data, the term "discuss" seems to be misused. Often, that which follows the introductory statement bears little resemblance to a real discussion, usually turning into a lecture, rapid-fire drill, or an "inquisition." In middle school science classrooms discussions are almost exclusively conducted at the lowest memory level described in Bloom's taxonomy of learning. Typically classroom discussions are so fast-paced that thinking time for students is almost non-existent. Most so-called classroom discussions tend to be lectures with a few questions interspersed here and there. Questions, which are used by teachers in some cases as disciplinary tools, seem designed to punish students who appear not to be listening to the "discussion" (i.e. lecture).

The data base for our assertions concerning typical classroom discussions is extensive, covering nearly 600 class sessions. A research project funded by the National Science Foundation was designed to determine the effects of increasing the pauses of teachers and students in classroom interaction. Without special training, pauses (wait times) in teacher-student dialogue are indeed short. Our work found that pauses average only 1.25 seconds between teachers' questions and replies by students (wait time 1) and only .55 seconds between the students' replies and the subsequent comments by the teachers (wait time 2). We asked 40 teachers to tape record a *discussion* in one of their classes each week for 15 weeks. We were surprised to find that most of the tape recordings were fast-paced *drill* or *review* for tests, with emphasis on low level memory questions, or were *lectures* punctuated by brief questions apparently designed to keep the students alert. Few could be classified as discussions or inquiry lessons having the intent of development of the intellectual processes of students. We also found that students typically do not ask questions in classroom discussions, nor are they encouraged to do so. Thus it seems that, while research has revealed that memory level drill and lecture are not the optimal facilitators of learning, teachers persistently follow these strategies.

We were able to help some of the teachers slow the rapid pace of their instruction by the introduction of a wait time feedback device in each of their classrooms. The device consists of voice activated switches, a variable timer and a system of red and green lights. A red light is activated when a person is speaking, while a green light signals whenever sustained silence occurs. The duration of the red light at the end of a question, response, or other pause controls wait time length. When 3 seconds have elapsed, the green light is activated to signal that it is appropriate for another participant to enter the discussion. Introduction of the wait time feedback device resulted in interactive behavior that included more extensive use of evaluative questions, longer student responses, and improved levels of student participation in discussion.

It was found that these results could be enhanced by using a process that we have labeled *supportive intervention*. In this procedure the study team listened to the recordings in a classroom interaction laboratory rather than doing analyses in the presence of the teachers. Notes were taken which emphasized teaching successes and suggested avenues for further professional growth. Behavior that was negative or contradictory was ignored in the comments prepared for sharing with the teachers. The term "criticism," with its negative implications of failures, was carefully avoided. Reinforcement was given for successful approximations of the 3 second wait times, operation at higher cognitive levels of thinking, and utilization of student interaction.

The results of supportive intervention were impressive. The wait times improved to means close to the 3-second criterion. In addition, the percentage of time that students were talking about topics relevant to the lessons nearly doubled and the mean length of students' statements (answers to questions, discussion comments, or questions from the students) increased by nearly 50 percent. Higher level questions, normally only 10 percent of the total, increased to nearly 50 percent, with many more divergent and evaluative questions being used.

Discussions with teachers who participated in our research revealed that teachers claim that they must move quickly due to three reasons. First, teachers expressed concern that there was so much content to cover that they could not take time for interaction. Second, the teachers felt that motivation would flag if they slowed the rapid-fire pace of their teaching to permit more student input. Third, they thought pausing would precipitate disciplinary problems in their classrooms. Paradoxically, the urge to cover more material results in less information being retained by students.

In sum, we have determined that effective use of wait time can result in spontaneous improvements in both cognitive and affective variables in the classroom. These changes are enhanced if wait time feedback is supplemented by supportive suggestions from persons who have carefully listened to tape recordings of classroom interaction. In an era of low teacher turnover and an aging teacher population, methods that effectively improve the skills of in-service teachers are of vital importance. It appears that monitoring wait times using an electronic device accompanied by skilled analysis of tape recordings and supportive comments does indeed provide an avenue to the improvement of teaching skills.

This research is described in an article "Wait Time and Questioning Skills of Middle School Science Teachers" by Swift and Dr. Gooding in the *Journal of Research in Science Teaching*, 1983, *20* 721-730. For further information on the availability of wait time feedback devices manufactured by Thought Technologies, Ltd., or information concerning supportive intervention techniques, contact: Dr. J. Nathan Swift, Department of Secondary Education, State University of New York at Oswego, Oswego, NY 13126.

Dr. J. N. Swift is Professor of Secondary Education and Dr. C. T. Gooding is Professor of Psychology and Associate Dean of Graduate Studies at the State University of New York at Oswego, N.Y. Both are members of the National Association For Research in Science Teaching, an organization that seeks to improve science teaching through research.

PUPIL BEHAVIOR AND MOTIVATION IN EIGHTH GRADE SCIENCE

By Ann C. Howe

What motivates junior high school pupils to spend their time productively in science class? Does increased effort really lead to higher achievement? In order to study these and other questions we made systematic observation of the behaviors of boys and girls in junior high school science classes. In all the classes studied teachers used an activity centered approach to teaching with much of the time spent in hands-on or laboratory work. Our sample included an equal number of boys and girls and black and white students. In addition to observational data we obtained scores on standard reading and mathematics tests and used final class grade as the measure of achievement.

We defined three categories of behavior. Active Learning Behavior was defined as any behavior, other than reading or writing, directly related to the assigned activity. This included setting up equipment, carrying out an experiment, observing an experiment or discussing the work with a partner. The second category was Passive Learning Behavior — listening to the teacher, reading or writing. The third category was Non-Learning Behavior, defined as any non-task oriented or non-productive behavior.

Our first finding was that mathematics and reading skills are the most important factors in science achievement at eighth grade level. Boys and girls who have poor basic skills when they enter eighth grade are not likely to succeed even when the class is based on active involvement. We found that the next most important factor in science achievement was Active Learning Behavior. We found no race or sex differences in behaviors — an interesting finding in view of the assumption held by many people that girls are less active than boys in school and that black students' lower achievement is due to non-attention in class.

We found that reading and math scores and active learning behavior were related to achievement for all groups.

But what motivates pupils to be active in class in productive ways, to engage in Active Learning as opposed to Passive Learning or Non-Learning behaviors? Many researchers who have studied pupil motivation have based their work on the assumption that pupils will direct their efforts toward achieving goals that they value. Therefore, if pupils value success they will work to achieve it. In order to study this question we asked pupils to answer questionnares to determine whether they valued success in school and particularly in science and whether they attributed success, when they attained it, to their own effort, to their ability, to the ease of the task or just to luck. Then we asked teachers to rate pupils on these variables and pupils responded to questions about their effort, the level of difficulty and the environment of that class.

We found that pupils of both races and sexes *do* value success in science and that they believe their parents and teachers value it also. There was little to suggest, however, that valuing success is translated into effective effort in the classroom except for one group, the black boys. For that group positive correlations were found between value of success and Active Learning, between teachers' valuing success and Passive Learning, and a negative correlation between teachers valuing success and Non-Attending. Apparently those in this group who value success *themselves* engage in more Active Learning behaviors and those that think *teachers* value success engage in more Passive Learning behavior.

Two sex differences in causal attributions were found; boys attributed success more to ability and girls attributed success more to effort. That is, boys think they succeed because they are bright and girls think they succeed because they work hard. There were no racial differences on this dimension. Many interpretations of this difference are possible, but we suggest the following. Attribution of success to ability is a sign of self-confidence, stronger in boys than in girls, that is not strongly related to actual ability and does not lead to more or less effortful classroom behavior. It is interesting that those who attribute success to ability do not attribute failure to lack of ability. Both attribution of success to effort and to ease of task are associated with increased Passive Learning, the traditional mode of classroom behavior. These pupils are "trying hard" by listening to the teacher and working on in-class assignments. Unfortunately for them, we did not find a relationship between Passive Learning and final grade.

Those who attribute failure to lack of ability do, in fact, have lower grades (i.e., they have more failure), lower SRA-Math scores (possibly a sign of lower ability) and engage in Active Learning less often. A similar pattern emerges for those who attribute failure to the environment (i.e., luck or other external forces). They engage in Active Learning less often, Non-Attending behaviors more often, and have lower SRA-Math scores.

We had expected to find that those who attributed success to effort would engage in more Active Learning behavior (i.e., put forth more effort) but this was not the case. We did find, however, that those who attributed failure to lack of ability, or outside influences, engage in fewer Active Learning behaviors, as if to say "What's the use?" A suggestive finding was the negative correlations between the pupil's rating of difficulty of classwork and the teacher's rating of ability and effort. This suggests that low-

achieving pupils see the work as too difficult but the teacher thinks they are not putting forth effort.

One unexpected finding was the lack of correlation between the teacher's estimate of pupil ability and the pupils' perception of the teacher's rating. This may indicate a lack of honest communication on the part of the teacher and could result in frustration for the pupils. The failure to find a significant correlation between value of success, attribution of success to effort and actual effort may be due to adolescents' inability to make the connection between the present and the long range future. If this is the case, teachers need to help their pupils make that connection by being more explicit in expressing their expectations and more straight forward in evaluating pupil progress.

This work was carried out by Dr. Vernon Hall, Syracuse University; Dr. Norman Lederman, SUNY-Albany and Dr. Ann Howe, North Carolina State University. Drs. Howe and Lederman are active members of the National Association for Research in Science Teaching, an organization that seeks to improve science teaching through research.